Risk Management for the NASA/JPL Genesis Mission: A Case Study

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Abstract. Processes, just like any product, are designed to meet a set of requirements. The Risk Management Process for the Genesis Project began with the basic requirement to meet NASA and JPL policies and standards. Meeting these basic requirements was not as challenging as trying to avoid process execution flaws observed in the practice in other applications similar to the JPL environment. In addition, there were new issues and changing emphases that required the process to continuously evolve as the project matured.

The process was designed to avoid pitfalls encountered by others as they have tried to implement Risk Management. A set of lessons-learned which covered the experiences of others, specific inputs from the project's Risk Manager, and the evolving needs of Genesis Project management guided the development of the process. This led to the necessity of a facilitated approach. The facilitated approach took advantage of the knowledge of the team members directly involved with the at-risk elements and supplemented them with the specialized skills and tools required for Risk Analysis.

The resulting process was successful in managing the risks to the project. Results varied as the process and project matured. In general, the results indicate a good return-on-investment for the risk management activity. In addition, new lessons-learned are being collected.

LESSON'S LEARNED

Previous Applications. Previous applications of Risk Management have generated the following Lessons-learned (Roberts, 1999).

1. The greatest risk driver is often overlooked.
2. Inappropriate attention may be given to one risk driver over others.
3. Often a risk driver will impact all facets of risk (cost, schedule, technical, etc.,) and the integrated result will be improperly estimated.
4. Often risks are managed by lists that are ranked by subjective qualitative measures resulting in excessive expenditure of risk management resources.
5. Risk Identification is the most critical step in risk management, yet is poorly done.
6. *"Faster, Better, Cheaper"*, or other competitive initiatives, exacerbate risks.

Genesis Process. The application to Genesis was designed to eliminate or mitigate the kinds of problems that have been previously observed. In order to fully understand the process, it is important to summarize the project environment in which it was implemented. Genesis is part of NASA's Discovery Program and is executed as a team partnership. Team members include the California Institute of Technology, Lockheed Martin Astronautics, Los Alamos National Laboratory, NASA's Lyndon B. Johnson Space Center, and the Jet Propulsion Laboratory. The challenge of risk management in the Genesis environment is to implement the process across physically separated organizations whose culture and internal processes varied. In the following, we present solutions intended to reduce or eliminate these observed problems.

SOLUTIONS

Devolved. Devolved means the actions, ***and*** the responsibility, accountability and authority are delegated downward as a matched, inseparable set. We use the term "devolved" rather than delegated, deployed, or allocated because the definition of devolved is much more restricted. The intent is to increase our confidence that we have done the best we can do to identify and manage risks by placing the responsibility at the appropriate level.

Other approaches such as oversight by an external organization are generally inefficient and ineffective – they don't "own" the risk. Requiring the person who must experience the consequence of the risk to be the risk owner is the best assurance that the risk will be managed. This places ownership and risk mitigation actions at the place in the project organization where the greatest knowledge of the risk lies.

This, of course, complicates the resolution of other risk lessons-learned such as trying to understand the total integrated effect across the project. It is not uncommon for one person's "few-days" at-risk schedule impact to become an integrated "few-weeks" total schedule impact. Thus, we needed to supplement with integration concepts.

Integrated. The process developed for Genesis recognizes the interactions between risk areas such as cost, schedule, and technical. That is, technical issues can drive schedule and then schedule drives cost. Also, what may appear to be a small schedule problem in one task area may be greatly exaggerated through the interaction with all the other tasks in the integrated network. Therefore, we integrated across risk areas as well as across project activities.

Integration was performed by the Project's Risk Manager who maintained the risk database, consolidated the risks, and integrated the risk impacts using various analysis tools.

Trained. There must be a consistent application and understanding of the processes and procedures from top to bottom. We also needed "buy-in" from all involved in the process. We needed to be sure that risk aversion was normalized across the project, that is, one person's "high" risk was equivalent to another person's "high" risk. This was accomplished through training. As a part of that training, we used expert facilitation, in a brainstorming environment, for the initial risk inputs.

Tailored to Project. Always, the first and foremost question to be addressed in any risk management process is: "What is to be Risk-Managed in this project?" Here, we are using the term "Project" to identify the complete set of activities necessary to produce a product. In this case, the product is a set of material samples obtained during exposure to the solar environment as it streams from the Sun and prior to interaction with the Earth's magnetosphere. This includes the science instruments, the Spacecraft Bus, the Sample Return Capsule, the launch vehicle, all aspects of space flight operations, and the recovery of the samples.

The very specific need to return the samples undamaged and contamination free, is a major requirement to the risk management process.

A second, and more important "risk to be managed", for the near-term, is the cost containment risk. NASA's new requirements for project management improvements as specified in NASA Program Guideline (NPG) 7120.5A require cancellation if a project exceeds its cost authorization by 15%. Missing the launch window would incur extensive costs. Thus, being ready to launch within the schedule target window is a primary driver.

Tailored to Organization. The organization has specific requirements and standards on the execution of risk management within the project. The Genesis Risk Management Plan was written to be fully compliant to both NASA and JPL standards.

The organization is also responsible for providing tools and other support to the project. The process must integrate these tools and supplement where needed. The Genesis web-based Risk Management Application was tailored to fit within the pre-existing web-based Risk Management System. The web based application allowed the various partners to easily input and update risks from their remote organizations into a common database.

Quantification. Quantification is absolutely necessary in order to manage the mitigation investments. We did this by building a Triage Procedure. The objective of the Triage Procedure is to sort out those risks that should be subjected to quantification. Our process first uses a qualitative procedure to evaluate risks and assigns them qualitative values of Likelihood and Consequence. The risks are tested against the Triage rules that filter out the ones that we need to subject to quantitative analysis. The purpose of the quantitative analysis was to improve the likelihood and consequence values of the significant risks and calculate project impact in terms of dollars or days. This information was used to manage the risk mitigation planning as well as to rank order the risks.

One of the most useful tools built into the analysis process was the Double Pareto box. This tool is a matrix of Risk versus Risk-Impacted activity. The individual risks are listed across the top of the atrix and each impacted WBS item is listed down the left side of the matrix. Each cell is filled with at-risk days or at-risk dollars. Then the matrix is sorted to collect the 20% of the risks that are causing 80% of the impact to the WBS items. It allows quick prioritization of which risks are the major drivers and which project activities are most impacted by those risks. The Double Pareto box provides focus for management attention.

Skill Mix. We were careful to manage the skill mix throughout the project. Project team members were responsible for risk identification, qualitative assessments and the risk handling approach because they would have the greatest knowledge and skill for these parts of the process. However, the integrated risk environment and the quantitative analysis was accomplished by experts having substantial experience with the risk management tools.

GENESIS TAILORED PROCESS

All of these considerations were carefully thought out and integrated into the risk management process for the project. A top-level description of the process is provided in Figure 1. The process has three fundamentally unique steps not generally found elsewhere. (1) The collection of confidence levels on the qualitative assessments for likelihood and consequence and the use of a Triage Procedure that used those confidence levels to make decisions on which risks were significant enough for detailed, quantitative analysis. (2) The use of analogous results from prior similar projects. This was very helpful early in the project prior to the availability of mature project estimates. (3) The use of a Double Pareto Box to focus risk actions on those tasks and risks contributing to 80% of the integrated risk impacts.

GENESIS RESULTS: RISK MANAGEMENT PROCESS PERFORMANCE

This section will discuss the individual steps in the process and present the lessons-learned against each.

Planning. The approach was developed to be fully compliant with NASA NPG 7120.5A. We believe that we did have some problems with understanding and buy-in from the project elements that could have been overcome with more attention given to the planning activity. Greater emphasis from the project and cooperation through collaborative development might have helped.

The training was effective for those who participated. However, there were some who were unable to attend because costs for training had not been included in the development plan. Those elements of the project did not have sufficient reserve to accommodate the loss of work. In some areas, only a few personnel were trained to keep costs within the plan. This is of concern due to the great leverage that risk management can have. We were very disappointed in the attendance and believe that we may have missed some risks and know that some risks were identified late due to a limited knowledge of the process, how to use it, and its value.

<u>Lesson-Learned:</u> To include sufficient resources in the planning activity to adequately provide for training.

Identification. Risk identification worked very well in the facilitated brainstorming exercises that were a part of the training, but fell short because of the limited attendance. The Project Risk Manager did the majority of the risk identification activity that occurred after the training. This was done by review, analysis, and constant interrogation to discover the risk items.

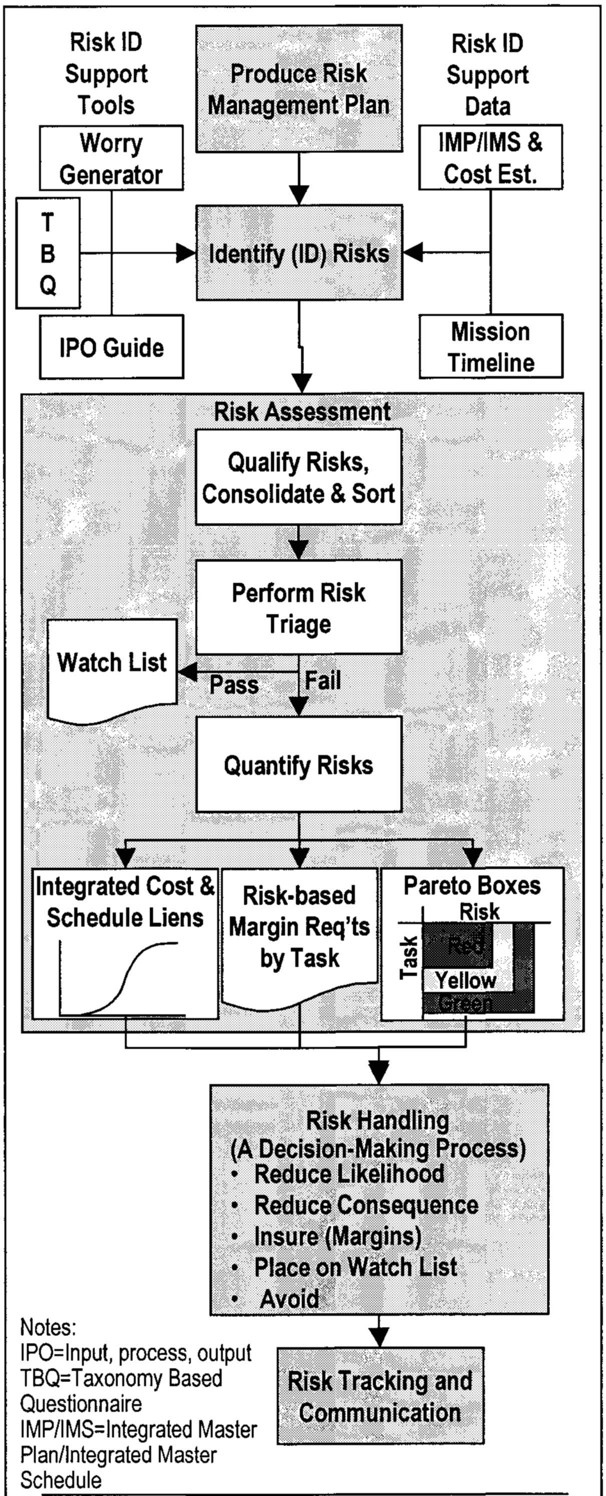

Figure 1 . Genesis Risk Management Process

One element of the project maintained their own risk tracking system separately from the Project's system. The reports, although sometimes useful, were not reporting risks as much as problems and issues. It was more reactive than proactive. Thus, it lacked the maturity of the mainline Genesis Risk Management process and caused concern as to whether all risks were being identified in a timely manner to implement cost effective risk mitigation plans.

This deficiency became apparent during the Subsystem and System CDRs. New risks were found during the reviews and old ones needed reassessment. Unfortunately, some rather significant problems were also found that should have been identified much earlier as "risks" if the proper maturity had been instilled into that element of the project. For example, a new development for a complex electronic card was beginning to experience schedule delays and cost overruns. This should have been predicted and identified earlier. As it turned out, the card was delivered late and impacted the critical path.

What is the lesson-learned? First of all, this reinforces the lesson regarding buy-in and training. There is also a lesson in the value of striving for early identification. The real value of risk management is the proactive effort to find potential risks early and deal with them before they become "Problems".

Lesson-learned. A strong position must to be taken by project management to enforce participation in the process. Also, the Risk Identification Form did not turn out as simple as planned. It was very detailed and we received complaints about its complexity. We need to presume that some folks were put off by the complexity of the form and that may have caused some risks to not be entered.

Lesson-learned. Keep the input form SIMPLE! If more data is needed, collect it in an interview session.

Assessment. The assessment consisted of two parts, (1) the qualitative risk assessment which assigned ordinal values of High/Medium/Low to the likelihood and consequence, and (2) the quantitative risk analysis which assigned actual probability distributions to the likelihood and consequence. The process included a Triage step. This step sorted the high risks and the medium risks having anything other than "high" confidence in the estimates for the ordinal values. This sorted set was subjected to quantitative analysis. Figure 2. Early in the project, when data was immature or non-existent, we used an analogy model to predict the risk probabilities for likelihood and consequence. As the project matured, we switched to collection of expert opinion for the analysis inputs. Prior to switching to project expert opinion, the analogy model was subject to challenge.

The actual assessment went very well. Four different tools were used: @-Risk Decision Suite©, @-Risk for Project©, Microsoft Project©, and Mainstay's STAR©. The problem we faced was the project's understanding and acceptance of the tools as capable of predicting the probable outcomes. In addition, the tools use project data as input and the quality of the output is obviously driven by the quality of the input.

So we had three project acceptance issues to address.

1. Verify the capability and applicability of the tools
2. Validate the project's input data
3. Validate the use of the analogy model.

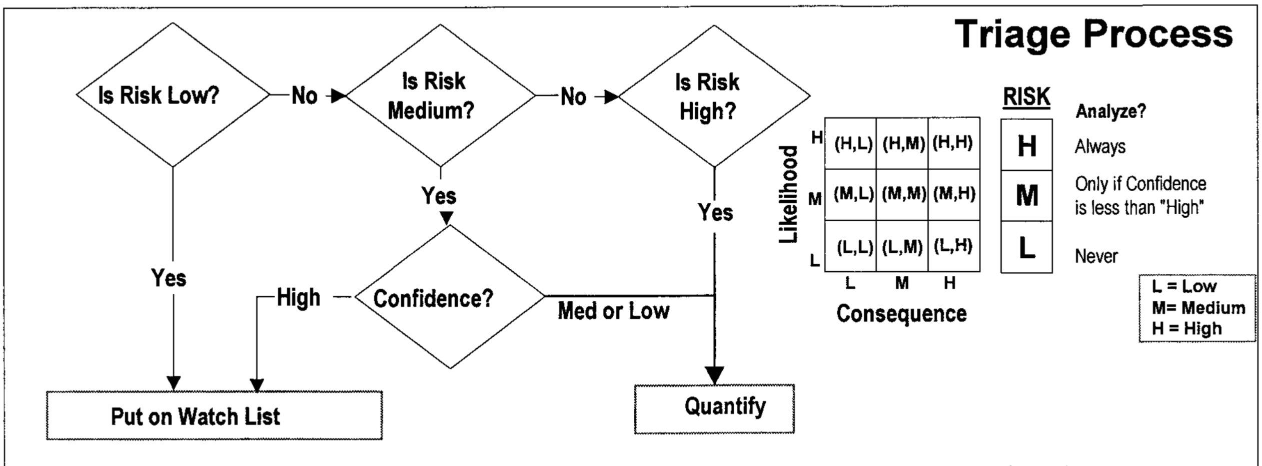

Figure 2 . The Risk Triage Process selects risks for the detailed analysis.

We did this validation at about the CDR point in the project. It was done via peer review. The review went very well and it did improve the process and improve the project's understanding and acceptance of the results. In hindsight, we should have done this early in the project. Quantitative risk analysis is not generally accepted because of distrust of the quality of the inputs and generally limited understanding of the analytical tools that are used.

Lesson-learned. Validation of the tools and input data needs to be done early in the life cycle of the project.

Handling. The risk handling was uneventful. It appears as though good decisions were made by the project as will be demonstrated in the section "Genesis Results: Project Benefits From Risk Management Execution". Having analytical data, models, and actual quantitative information on the risk impacts in days and dollars along with confidence intervals greatly facilitated decision-making. Decisions were very appropriate and timely, allowing early actions to be made to reduce risk impacts.

Lesson-learned. A proactive approach is extremely valuable. The analysis presented data and information to make timely decisions allowing the project to be proactive rather than reactive in risk management.

Communication and Tracking. One of greatest problems that we encountered was the development and presentation of information in a way that was useful for project management. The type of analysis and the data products are atypical of what most projects normally see. It took a number of attempts to get the pertinent data condensed into useful information for project decision-making and actions.

Lesson-learned. Devote more effort to develop and tailor the process and the information that it produces to match the project and its management culture and styles, and do it early.

GENESIS RESULTS: PROJECT BENEFITS FROM RISK MANAGEMENT EXECUTION

Direct Benefits. Direct benefits are those benefits that result from the direct application of risk management techniques to tasks or process steps. Indirect benefits, discussed in the next section, are those that result from the need to support the quantitative assessments.

The direct benefits are substantial reduction of risks at minimal investment. This was possible by being proactive and catching many risks before they became problems. As Figure 3 displays, the first risk assessment was accomplished at the project Preliminary Design Review (PDR). Almost half the high risks were reduced to mediums and lows within a few months by proactive actions designed to reduce likelihood of occurrence. The "jump" in risks in the May-June 1999 time frame is due to the influx of maturing data that occurs during a project's major design reviews. In this case, the project's Critical Design Review.

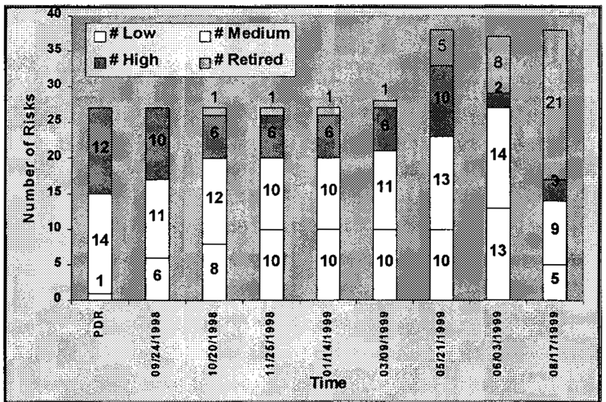

Figure 3. The shrinking High risks demonstrate effectiveness of the process.

While Figure 3 demonstrates the effectiveness of the risk management process in a qualitative sense, we also have quantitative results. The risk management process that was employed used a Triage Procedure to segregate out risks to be subjected to a more rigorous analysis process. As we collected the qualitative risk inputs, we also collected confidence values for each likelihood and consequence estimate. All high risks, regardless of the confidence of the likelihood and consequence estimates, were passed to the analysis step. All medium risks whose confidence estimates for likelihood and consequence were less than "high" were also subjected to analysis based on the assumption that because of the less than perfect knowledge of the risk estimates, these "mediums" may, in reality, be "high".

The risks that passed Triage for analysis were input into the Mainstay STAR Risk Analysis Tool. The resulting schedule calculation was plotted to show the probable threat to the launch date if no action was taken to mitigate it. Figure 3 shows the substantial impact of the risk abatement actions taken over time.

How to Read Figure 4. The vertical axis is the probable launch date. The horizontal axis is the date of analysis. The "Ready Early" band, indicated by gray crosshatching in figure 4, is bounded at the top by the initial planned project date when all elements are stacked and ready to launch. The "Launch Ready" band, the clear band in the figure, is the Launch Window. The "Missed Launch Window" band, the lower band in the figure that begins at launch window closure, means significant project delay and associated cost increases. The two plotted lines represent the continuously updated plan (the upper one) and the stochastic results from the quantitative risk analysis (the lower one). The plan date starts at the top of the Ready-Early (gray crosshatch) band at project start and is an output of the actual project plan. It will change as problems or risks manifest themselves and things need to be re-planned.

The risk result is the lower line that starts deep down in the Missed-Launch-Window band. The bars around the plotted point show the 20th and 80th percentiles where the plotted point is the 50th percentile. As the plot shows, early and proactive risk management has had significant impact on being able to meet the launch window.

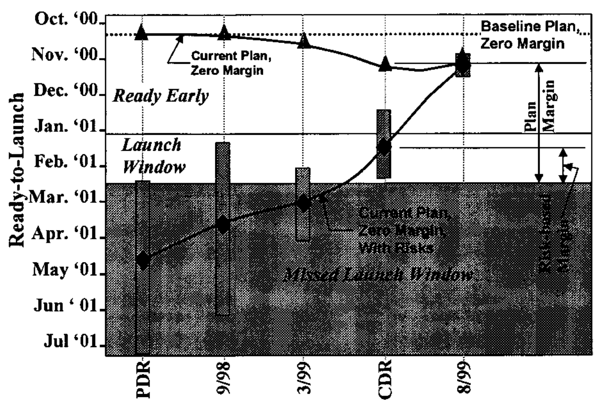

Figure 4 . The quantitative risk analysis clearly demonstrates the project's success in managing risk. The risk threat of 6 months has been successfully mitigated.

Indirect Benefits. The preceding paragraphs discussed the direct benefits of the Genesis Risk Management process. However, there were substantial indirect benefits as well. These benefits resulted from the demand for quality project data to support the quantitative risk analyses. We had made the decision in the beginning that we were going to use quantitative analysis in all cases where it was justified. This was important in order to improve the quality of our decisions. Quantitative risk analysis requires quality inputs such as an integrated schedule with accurate representations of the task constraints and relationships.

When we initiated the risk analysis, various networks and schedules existed in "pockets" of the project but had not yet been combined into an integrated network and schedule. Having an integrated schedule is not only critical to the risk analysis but also very important to the overall successful management of the project. The Genesis risk management team worked with the project's planners to build the initial integrated network which they maintained from that point on. The integrated network served many useful purposes to the project much beyond the needs of the risk analysis.

Lesson-learned. The indirect benefits of quantitative risk analysis due to the demand for quality project management data are as valuable as the direct benefits.

EVOLVING RISK MANAGEMENT

In the March to June 1999 time frame, the project was performing its subsystem and system Critical Design Reviews (CDRs). The "continuous" nature of the risk management process took advantage of the wealth of data available during these reviews. New risks were identified, some were retired and some were lowered in value. A substantial number of the new risks were in-flight risks that were identified as mission operation plans became available. (Refer back to Figure 3.) With the availability of the flight operations data available at CDR, we were able to hold brainstorming sessions and discussions on what can happen in each stage of the mission; thus yielding new risks. Also, it provided the opportunity to take some very effective mitigation actions as demonstrated by the sharp drop in high risks.

Subsequent to the CDR, our risk management activity was shifted to focus on the Assembly, Test and Launch Operations (ATLO) activities. In addition to "real" risks we began to accumulate some "*problems*" in the project. The difference between a problem and a risk is the likelihood. Things that are certain or near certain are "problems" and generally we did not want to encumber the risk management process with problems. However, some problems have uncertain outcomes and thus are very suitable for analysis by the same tools and techniques used for risk analysis. In the most recent risk assessment, we included all risks and all problems having uncertain outcomes. This provided information that is useful in mitigating all possible consequences.

The point that needs to be made from the preceding paragraph is that the risk management activity is more than just "continuous", it also "evolves" with the project. It changed with changing project foci and maturing project data. The types of changes experienced were: changing risk procedures, alternative risk analyses, and different tools. Figure 5 is intended to illustrate the evolutionary nature of the process. We expected evolution to occur and were prepared, but were not sure from the onset just how this would manifest itself. The results are a very useful lesson-learned.

Lesson-learned. Expect the risk management process to grow with the project and its ever-maturing needs.

Risk Handling Focus. In the beginning, most of our focus in risk handling is to reduce likelihood. Early on there is great leverage in small expenditures to ensure that the likelihood of occurrence is reduced. An example was the lack of recent experience of the team on spin-stabilized spacecraft. The possible risks due to design errors rippled throughout the entire system, including software. The expense to hire and staff the team with seasoned spin-stabilized design experience was very small as compared to the probable outcome otherwise. Later on, as new risks were identified, managing likelihood became more and more of a challenge because of the ever shrinking time-to-respond. There was then a shift to mitigating consequence. An example is that for a number of the mission risks, we had to develop "operational work-arounds"

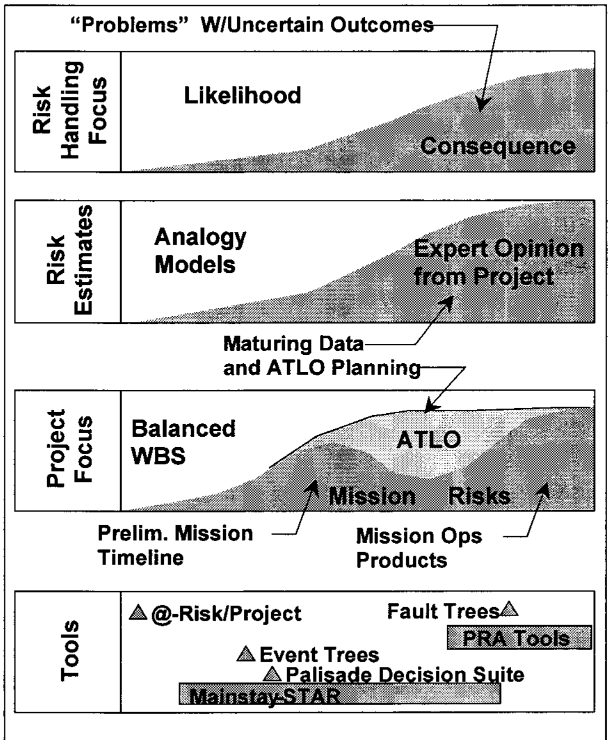

Figure 5. The risk assessment processes evolved through the project cycle as project needs and project data maturity evolved.

Risk Estimates. When we first began, we used analogous experience to generate the risk likelihood and consequence values. This involved using a database comprised of 354 NASA flight experiments and space missions. As the project matured, the validity of those analogies was challenged as to whether or not they were better risk estimators than the maturing data within the project. The risk analyses, subsequent to the CDR, were developed using expert data supplied by project personnel.

Project Focus. Prior to CDR, we examined all areas equally for risk and took mitigation actions as appropriate. As CDR passed, we had just about done all that we could for the tasks underway so we focused-in on the next major activity, ATLO. The fabrication of the hardware elements were well under way, so we had a lot of mature knowledge about them and we also had greatly improved planning data for ATLO. Thus, we concentrated our efforts at a close look into ATLO and reduced our attention to the other project elements. When we have finished "wringing-out" ATLO, greatly improved data will be available for mission operations and we will shift focus again.

Tools. In the beginning, we used simplified tools for project cost-schedule-technical risk analysis such as Palisade's @-Risk for Project. As the project matured, we switched to more sophisticated tools such as Mainstay Software's STAR. And, likewise, as we moved into mission risks we began using spreadsheet tools with Palisade's Decision Suite. As more project data is available for mission operations, we will switch to probabilistic risk assessment tools. Sapphire is a typical candidate.

SUMMARY

In summary, we collect and restate the new lessons-learned:

1. To limit risk management training because of the training cost, is a false economy.
2. A very strong position needs to be taken by the project management staff to enforce participation in the process.
3. Keep the input form SIMPLE! If more data is needed, collect it in an interview session.
4. Validation of the tools and input data needs to be done early in the project.
5. Being proactive is extremely valuable The analysis presented data and information to make timely decisions allowing the project to be proactive rather than reactive in risk management.
6. Devote more effort to develop and tailor the process and the information that it produces to match the project and its management culture and styles, and do it early.
7. The indirect benefits of quantitative risk analysis due to the demand for quality project management data are as valuable as the direct benefits.
8. Expect the risk management process to grow with the project and it's ever maturing-needs.

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BIOGRAPHIES

Barney B. Roberts. Mr. Roberts is the Director for the Futron Risk Management Center of Excellence. His role in that position is to formalize the risk management practices, procedures and tools that he has successfully developed and utilized in assisting customers in understanding and managing risk for the past 4 years. He has developed advanced techniques for cost-technical-schedule risk management assessments. He assists clients in managing and mitigating risks.

Prior to coming to Futron he was the Manager of the Planet Surface Systems Office, at the Johnson Space Center (JSC). During his last 10 years at JSC, he coordinated the strategic planning and development of concepts and operational strategies for human outposts on the Moon and Mars. He participated in, and led, several international studies for advanced missions.

Mr. Roberts was a significant contributor to the development of the Space Shuttle. He was on the engineering staff of JSC since 1962, involved in such diverse areas as project management, system engineering, hardware and software development and certification, crew training, aerodynamic test and analysis, flight mechanics, flight control design and analysis, rocket engine analysis and test, computational fluid mechanics.

Mr. Roberts has pushed the state-of-the-art in many technical areas and is well published in the professional literature. He has many awards including a patent for an aerobraking orbital transfer vehicle.

Richard B. Bennett. Mr. Bennett is the Risk Manager and Mission System Engineer for the Genesis Project. He manages the mission engineering team and performs global system engineering optimization across the entire project. Prior to the Genesis assignment, he was Team Leader of the Advanced Projects Design Team (Team-X) where he provided daily management and guidance for a seventeen-member space mission conceptual design organization

Prior to joining JPL, Mr. Bennett was the satellite system integration, test, and Launch Operations Manager for Hughes Aircraft Company's three-axis stabilized communications satellites (HS-601), AUSSAT B contract. He also served as assistant Department Manager of 80 scientists, engineers and technicians involved in the design and development of satellite and space shuttle avionics control electronics.